High Efficiency, Zero Emission, Low Cost H_2-O_2-Ar Engine

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While gasoline-hybrid vehicles reduce CO_2 emissions and petroleum use, the goal of complete elimination of automotive petroleum use and the resulting emissions will demand hydrogen-fueled vehicles. Fuel cells are thought necessary to power hydrogen vehicles due to their high efficiency (~50%). The current high cost of fuel cells is the greatest barrier to hydrogen vehicle commercialization.

We are investigating the feasibility of a hydrogen (H_2) spark-ignited internal combustion engine that promises the highest efficiency of any engine ever built. This engine can have the high efficiency and zero emissions of a fuel cell, enabling affordable and practical vehicles necessary for a successful transition to carbonless transportation. Our concept for hydrogen engines consists of mixing H_2 and oxygen (O_2) with argon (Ar) in the combustion chamber. Argon has a high specific heat ratio (γ = 1.67, compared to γ <1.4 for air). According to basic engine theory, this high value of γ can considerably improve engine efficiency. Theory predicts an ideal efficiency approaching 75% (Fig.1), and in practice we anticipate 50% once heat transfer and friction losses are included. Argon can be recycled in a closed loop (Fig. 2), so that there is no need for "refueling" Ar.

Fully realized, the H_2-O_2-Ar engine would represent a transformational

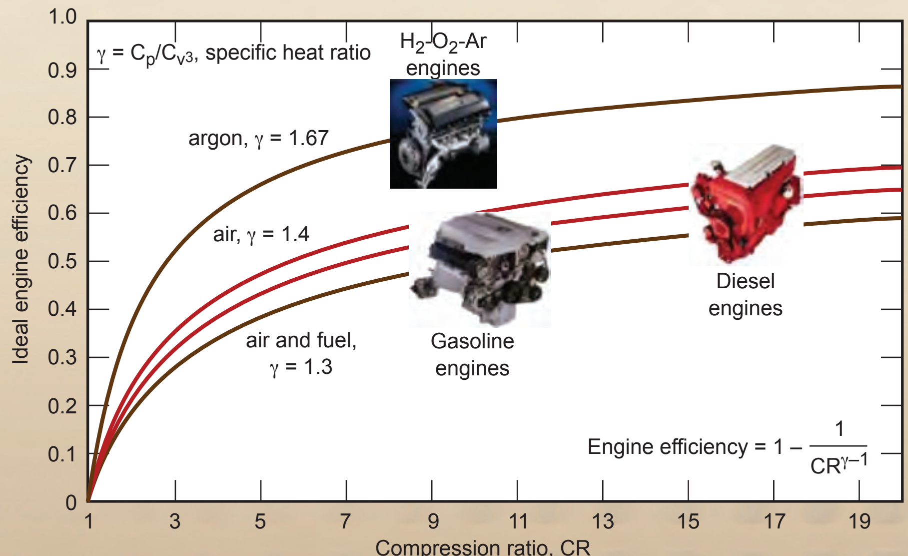

Figure 1. The efficiency of an Otto-cycle internal combustion engine. Ideal engine efficiency is dependent on the compression ratio and the specific heat ratio, γ, of the gases in the cylinder. Using Ar as a working fluid allows for significant gain in the thermodynamic efficiency of the cycle.

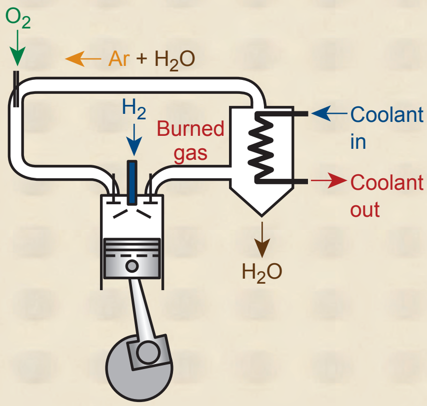

Figure 2. The H_2-O_2-Ar engine. The engine achieves high efficiency by operating with Ar in a closed loop, adding H_2 and O_2 for combustion, and condensing out combustion product water.

breakthrough in the use of H_2, delivering a vehicle power plant with similar performance to a fuel cell, but with significantly reduced cost. This innovation rethinks how an engine is operated by adapting current technology, does not need breakthroughs in materials technology to be successful, and is deployable in the near term. This engine concept has many advantages:

1. High efficiency: argon gas as the working fluid in an internal combustion engine has the most favorable thermodynamic characteristics.
2. Zero emissions: carbon and nitrogen are eliminated from the engine system, avoiding compounds that promote both global warming (CO_2) and local air pollution (CO, HC, NO_X).
3. Affordability: the engine has no significant cost premium since it can be made entirely from existing engine technology.
4. High power density: the closed loop allows the engine to be effectively supercharged with little parasitic losses.
5. Argon abundance: Ar is inexpensive and abundant and could readily meet the demand for a fleet of H_2-O_2-Ar powered vehicles using recirculating Ar.

Project Goals

Our work focuses on demonstrating the virtues of the H_2-O_2-Ar engine concept. Due to its unique combustion characteristics, hydrogen is the only practical fuel for this concept. Hydrogen fuel enables engine operation spanning the broadest possible range of compositions with O and Ar, and the easily condensed combustion product (water) makes operation at high pressures and attendant high power density possible. This fuel ratio flexibility also means an extensive space of compositions must be evaluated over the operational range needed for a practical engine.

Relevance to LLNL Mission

The goals of this project are aligned with LLNL's missions in energy and the environment.

FY2009 Accomplishments and Results

We have developed a science-based capability to identify appropriate regions of operation for a H_2-O_2-Ar engine. As compression with a high specific heat ratio leads to high pressure and temperature during the compression stroke, we developed and validated a detailed chemical kinetic mechanism for hydrogen combustion especially tuned for this previously unexplored thermodynamic space. This mechanism was then applied within a systems model of the engine that confirmed its potential for very high efficiency and low emissions for closed cycle operation. Ongoing work focuses on detailed fluid mechanics modeling of H_2-O_2-Ar engine combustion.

In a parallel task, we converted a variable compression ratio CFR engine to H_2-O_2-Ar operation (Fig. 3) and extensively tested the range of chemical compositions and compression ratios that may maximize efficiency. Preliminary efficiency results are limited by knock (fuel autoignition ahead of the spark-initiated flame). Knock avoidance calls for operation at higher speeds in overexpanded engines (asymmetric engine cycle with higher expansion ratio than compression ratio), and this is the direction of current investigation. In the longer term, high-pressure hydrogen direct injection during the compression stroke could prove a straightforward approach for eliminating engine knock.

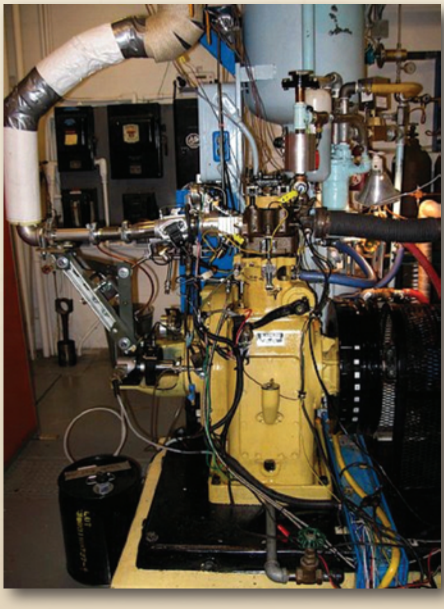

Figure 3. H_2-O_2-Ar operation. A flexible and robust single cylinder variable compression ratio engine is critical to optimizing the performance of the combustion system, particularly when operating an engine in a brand new regime like that of the H_2-O_2-Ar engine.